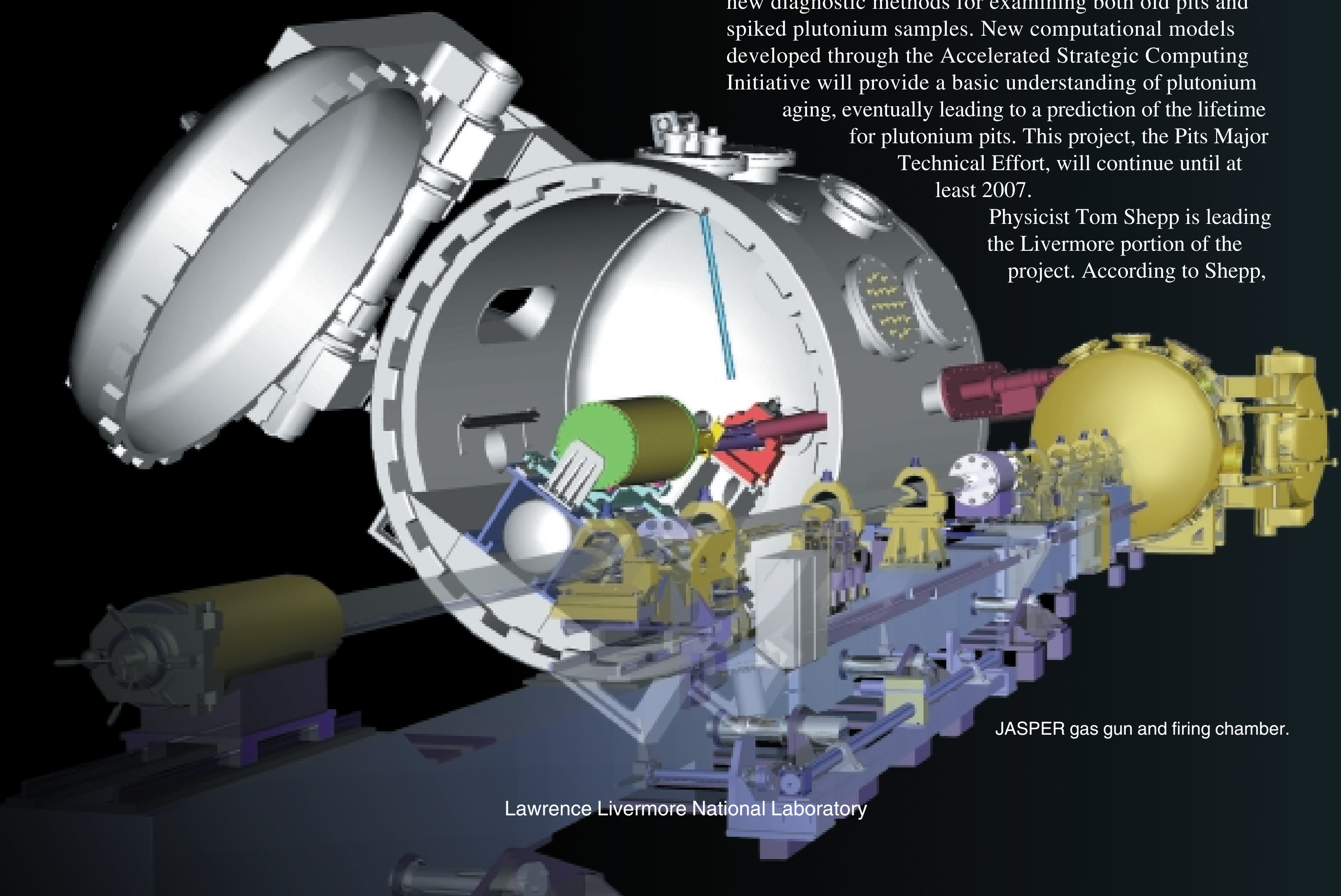
It's the Pits in the Weapons Stockpile

WITH no replacements being built for them, the nuclear weapons in the stockpile are sitting there, steadily aging. Materials inside them may be developing minor sags and wrinkles, just as we humans do over time. In the mid-1990s, in the first years after nuclear testing stopped, the Department of Energy established an Enhanced Surveillance Campaign to determine whether those sags and wrinkles were indeed developing and, if so, whether they would affect the safety and ultimate performance of the weapons.

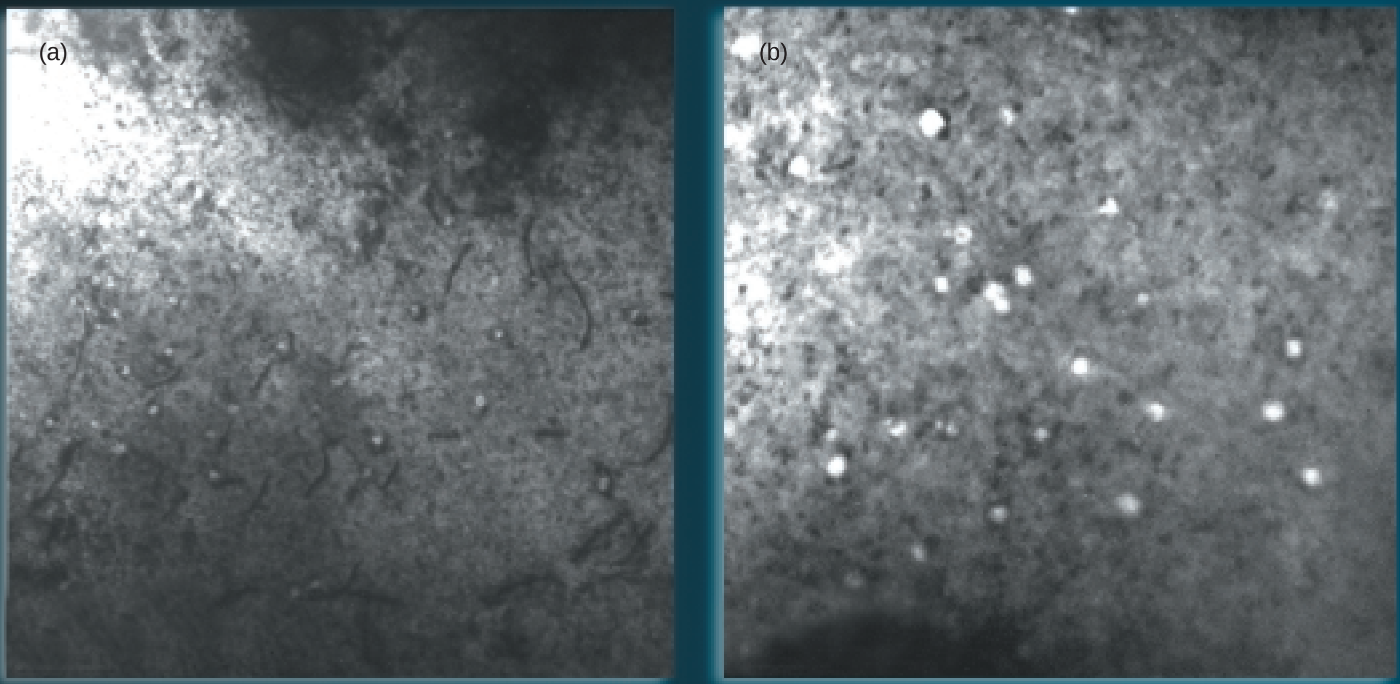
The Enhanced Surveillance Campaign is a part of the Stockpile Stewardship Program managed by DOE's National Nuclear Security Administration (NNSA). The detection and prediction of changes in an aging stockpile are among the most challenging and technically engaging aspects of stockpile stewardship. In the effort to understand stockpile aging, the Livermore and Los Alamos national laboratories joined forces with two NNSA plants, Pantex and Kansas City, to examine the pits inside nuclear weapons. The pits are shells of plutonium that play a key role in the performance of a nuclear weapon. The energy released when the plutonium atoms fission, or split, helps to start the huge fusion explosion of a modern thermonuclear weapon. Knowing how the pit changes as it ages is critical to predicting the performance of weapons in the stockpile.

Most pits in the U.S. stockpile are now 10 to 20 years old. NNSA wants to be able to project their lifetime to 60 years so decision makers will know what to expect as the pits age and whether they will still be safe and reliable. In response to that challenge, Livermore and Los Alamos scientists developed a way to spike weapons-grade plutonium to prompt it to age as much as 16 times faster than normal. At the same time, some of the oldest pits in the stockpile are being examined to establish a baseline against which the accelerated aging samples can be measured. Researchers are also developing new diagnostic methods for examining both old pits and spiked plutonium samples. New computational models developed through the Accelerated Strategic Computing Initiative will provide a basic understanding of plutonium aging, eventually leading to a prediction of the lifetime for plutonium pits. This project, the Pits Major Technical Effort, will continue until at least 2007.

Physicist Tom Shepp is leading the Livermore portion of the project. According to Shepp,



JASPER gas gun and firing chamber.



Samples of plutonium from the stockpile were subjected to isochronal annealing to induce the growth of voids. This sample was annealed at 400°C for one hour. (a) A look at 400 nanometers of material. (b) A closer view of just 200 nanometers of plutonium, in which minute voids are clearly visible.

"We are working to protect the health of the stockpile by providing advance warning of manufacturing and aging defects. NNSA especially wants to know whether they will need to build a facility for manufacturing new pits." NNSA's former pit production plant at Rocky Flats has been closed for many years, and reopening it is not an option. If pits are aging unacceptably, they will have to be replaced, necessitating construction of a modern manufacturing plant.

The Aging Process Up Close

Plutonium experts have two major concerns about aged plutonium: corrosion reactions and the results of self-irradiation. Most Livermore research is concerned with self-irradiation. When plutonium decays spontaneously, it emits an alpha particle (a helium nucleus) to become uranium. The heavy uranium atom recoils, displacing other plutonium atoms and disrupting the surrounding microstructure.

Says Shepp, "Spontaneous decay creates a cascade of chaos. We know that most of the helium atoms return to their old homes, but some don't, leaving microscopic voids behind. When they find new homes, they cause the pit to swell ever so slightly and may change the dynamic mechanical properties of the pit material. Over time, changes in the density, shape, and mechanical properties of the pit may affect the overall performance of the weapon."

Two machines at Livermore have been particularly useful for examining plutonium samples from the stockpile for material changes that result from self-irradiation. One is the new 300-kiloelectronvolt field-emission transmission electron microscope (TEM), the best one in the DOE complex. The new TEM is providing a better understanding of the microstructural evolution and stability of plutonium as a function of age and deformation. The other machine is the three-dimensional positron microprobe, which has the highest spatial resolution of any positron analysis system in the world. Positron annihilation lifetime spectroscopy can detect the size, location, and concentration of possible voids in naturally aged plutonium. (See *S&TR*, March 2001, pp. 23–25, and December 1998, pp. 13–17.)

Experiments by Livermore scientists on the Los Alamos gas gun as well as nonnuclear tests of plutonium at the Nevada Test Site are supplying more data points for the dynamic properties of stockpile pits. These measurements help assess how aging affects mechanical properties, including the equation of state, dynamic tensile fracture (spall), work hardening, yield strength, and generation of defect structures.

In another set of experiments, plutonium is cooled to near absolute zero and then cycled to higher and higher temperatures in a process known as isochronal annealing. The process damages plutonium and provides scientists with a fundamental understanding of the behavior of damaged plutonium.

These data come together to create more accurate models that can predict aging effects, overall performance, and the safety of pits and the weapons that contain them. Livermore has produced the first simulations of the quantum molecular dynamics of plutonium to study what is happening to individual atoms over very brief time periods. At the other end of the time spectrum, Monte Carlo statistical analyses examine a representative selection of the millions of interacting atoms and their daughter particles over the long-term processes of void creation and resulting swelling.

A Time Machine for Plutonium

These same experiments will also be performed on spiked plutonium alloys. If typical weapons-grade plutonium, plutonium-239, is spiked with some plutonium-238, which decays more quickly, the self-irradiation process dramatically picks up speed. If 5 percent of the plutonium-239 is replaced with plutonium-238, the sample will age 11 times faster than normal plutonium-239. Aging can be accelerated by a factor of 16 over normal aging processes if 7.5 percent of the sample is plutonium-238. A useful measure of acceleration aging is defined as the number of years required to reach a radiation dose that results in 10 displacements per atom. Weapons-grade plutonium normally takes 100 years to reach this dose but will need just 6.25 years if it is spiked with 5-percent plutonium-238.

The first batch of 7.5-percent-spiked plutonium was created in May 2000 at Livermore's Plutonium Facility (see *S&TR*, March 2001, pp. 4–12). In 2004, researchers will begin to study batches of spiked plutonium that have "aged" 60 years, the lifetime NNSA hopes to achieve. In fact, this accelerated aging process will allow studies of samples that have aged well beyond the ages of the oldest plutonium pits in the stockpile.

New Diagnostics and More Information

Over the next few years, several new diagnostic tools will be deployed at Livermore, Los Alamos, and the Pantex Plant. They include a high-resolution computed tomography system that Livermore is enhancing for use at the Pantex Plant. Livermore is further developing laser-shock diagnostics for pit surveillance. And its JASPER (for Joint Actinide Shock Physics Experimental Research) gas gun will come on line at the Nevada Test Site in about a year for shock tests of plutonium.

Shepp says, "During the first years of the project, we were getting ready by preparing the spiked alloys and starting the baselining process. Now we're beginning to see results." During the upcoming year, the team will validate the accelerated aging methodology by measuring aged samples against pit samples of comparable age from the stockpile. At the same time, Livermore and Los Alamos will finish characterizing the oldest pit materials of the most common pit type.

All studies to date indicate that the U.S. nuclear arsenal is robust and shows few effects of aging. Identifying the time scales of plutonium deterioration is critical for maintaining the continued safety and reliability of the stockpile.

—Katie Walter

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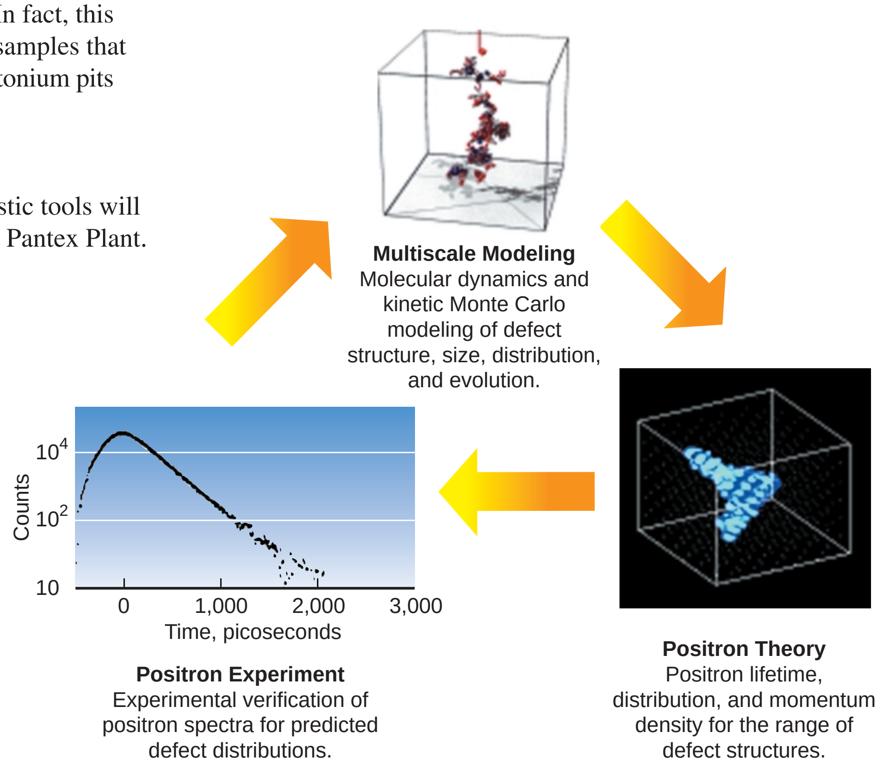

To better understand damage to plutonium weapon pits, Livermore scientists integrate modeling, theory, and experimentation. In this example, experiments with the positron microprobe supply data for better models of defects at various time scales, which leads to improved theory about how best to use positrons to predict defects. Better theory in turn makes for better experiments and thus better models, in a virtually endless loop.